# A New Conceptual Framework for Petroleum Genesis: Philosophical Reconsiderations of Organic-Inorganic Interactions


## Abstract

The debate over petroleum origins has been framed within a dichotomous paradigm of biogenic versus abiogenic theories. This study examines the conceptual limitations of such oppositional approaches and explores an alternative framework that reconceptualizes the role of organic matter.

**The central proposition is to consider sedimentary strata as natural reactors where organic catalytic systems facilitate the conversion of inorganic carbon sources into hydrocarbons.** In this framework, organic matter functions not as traditional "feedstock" but as a **sustainable catalyst**, while biomarkers could be interpreted as 'signatures' of these catalytic processes.

We philosophically examine how such a conceptual shift might reconcile with existing geochemical observations and provide new perspectives for contemporary CCUS technology development. This discussion emphasizes **conceptual possibility exploration** rather than empirical validation, presenting thought experiments for future research directions.


## 1. Introduction: Philosophical Background of the Petroleum Origins Debate

### 1.1 The Dichotomous Structure of Existing Paradigms

Scientific discourse on petroleum origins has been characterized for the past century by opposition between two major perspectives. The biogenic theory, based on paleontological evidence and the presence of biomarkers, understands petroleum as a metamorphic product of ancient organisms. In contrast, the abiogenic theory argues for the geochemical formation of petroleum based on thermodynamic stability and deep geological conditions.

**But is this dichotomous approach sufficient for understanding the nature of petroleum?** According to Kuhn's (1962) paradigm theory, scientific innovation often arises from perspective shifts that transcend existing conceptual frameworks. The petroleum origins debate could similarly open new horizons of understanding through such conceptual reconstruction.

### 1.2 Ontological Questions About the Role of Organic Matter

The ontological status of organic matter in existing discussions remains unclear. While treated as "feedstock" in biogenic theory and "contaminant" in abiogenic theory, **have other potential roles that organic matter might play in chemical processes been sufficiently explored?**

With advances in catalytic chemistry, we have gained more sophisticated understanding of how matter participates in reactions. **What if organic matter in strata functions not as simple reactants or products, but in a catalytic capacity?** Such a perspective could open new possibilities for integration that resolve existing oppositions.

## 2. An Alternative Conceptual Framework: The Stratal Reactor Model

### 2.1 Core Elements of Conceptual Transformation

**What if we understood strata not as mere storage spaces, but as natural reactors where complex chemical reactions proceed?** From this perspective, each component of the strata could be reinterpreted as follows:

- **Inorganic carbon sources ($CO_2$, $CH_4$)**: Primary reactants
- **Organic matter**: Catalytic systems that facilitate and regulate reactions
- **Stratal conditions**: Natural reaction vessels providing reaction environments
- **Metal ions**: Active centers functioning as co-catalysts

### 2.2 Multifaceted Roles of Organic Catalytic Systems

In this framework, organic matter could perform the following complex functions:

#### A. Role as Reaction Initiator

Hypothetical mechanism:
Organic matter → Initial $H_2$ release → Providing starting point for inorganic carbon activation

#### B. Function as Molecular Template

Possible process:
Specific organic molecular structures → Induction of similar hydrocarbon synthesis

#### C. Action as Reaction Environment Regulator

Expected effects:
pH regulation, redox condition optimization, metal ion chelate formation

### 2.3 Reevaluation of Geological Hydrogen Supply Mechanisms

Recent studies (Merdith et al., 2023; Ross et al., 2025) reporting geological hydrogen generation mechanisms can be reexamined within this framework:

**Hydrogen supply through serpentinization:**

$2(Mg,Fe)_2SiO_4 + 3H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + (Mg,Fe)(OH)_2 + H_2$
Annual global production: $4.2\text{-}24\times10^7$ kg $H_2$

**What synergistic effects might emerge when these geological processes combine with organic catalytic systems?** If organic matter catalytically facilitates the conversion of $CO_2$ to hydrocarbons using this hydrogen, it could explain observed petroleum characteristics in novel ways.

## 3. A New Interpretation of the Biomarker Problem

### 3.1 The "Catalytic Signature" Hypothesis

One of the greatest weaknesses of existing abiogenic theories has been difficulty explaining the presence of biomarkers in petroleum. **But what if we understood these as "traces of catalytic processes"?**

**Extending Thomas Gold's deep biosphere hypothesis (1992) for consideration:**

- Thermophilic microorganisms in the crust function as part of catalytic systems
- Their biomolecules guide the formation of specific hydrocarbon structures during catalytic processes
- Consequently, biomarkers are preserved as "molecular signatures" of catalytic activity

### 3.2 Reinterpretation of Concentration and Distribution Patterns

Characteristics of actually observed biomarkers:

- **Concentration**: ppm to 100 ppm levels (trace amounts relative to major components)
- **Stability**: High preservation over geological time
- **Selectivity**: Preferential preservation of specific structures only

**How well do these patterns align with the "catalytic signature" hypothesis?** Catalysts inherently function in small quantities and tend to maintain structural characteristics even after reactions. Therefore, the observed characteristics of biomarkers could be more naturally explained from this perspective.

# 4. Intersections with Modern Technology: New Perspectives on CCUS

## 4.1 Technological Mimicry of Natural Processes

**If strata actually function as natural reactors converting inorganic carbon to hydrocarbons, could we artificially enhance or mimic these processes?** This could provide completely new directional approaches to currently prominent Carbon Capture, Utilization, and Storage (CCUS) technologies.

## 4.2 Nickel-Platinum Group Element Enhanced Catalytic Systems

Recent nickel-platinum group element-based catalytic technology developed by the UT Austin research team (2024) can be reevaluated within this framework:

Reaction condition optimization:
Temperature: 100-150°C (50% reduction from previous 300°C)
Pressure: 150-300 bar
Catalyst: Nickel + organic support + clay minerals

**How effectively could such artificial systems mimic natural stratal reactors?** And what design principles might we learn from natural processes?

## 4.3 Thought Experiments on Economic Viability and Feasibility

Hypothetical economic analysis:

Processing costs ($/ton $CO_2$):
- $CO_2$ capture: $35
- Catalytic system: $20 (utilizing organic supports)
- Operating costs: $25
- Total costs: $80/ton

Potential revenue:
- Petroleum production: 0.4 barrels/ton $CO_2$
- Oil price $80/barrel → $32/ton $CO_2$
- Carbon credits: $50/ton $CO_2$
- Total revenue: $82/ton $CO_2$

**Of course, this is a thought experiment based on very optimistic assumptions.** However, what these calculations demonstrate is that there may be value in exploration, even within the realm of conceptual possibilities.

# 5. Philosophical Implications and Scientific Methodology

## 5.1 Reductionism vs. Complex Systems Thinking

Existing petroleum origins debates can be seen as somewhat based on reductionist thinking. That is, there has been a tendency to seek single causes: **"petroleum comes from organic matter" or "from inorganic matter."**

**But from a complex systems theory perspective, might petroleum be an emergent phenomenon arising from interactions among various elements?** In this case, understanding the roles of organic and inorganic matter as complementary rather than oppositional would be more appropriate.

## 5.2 Scientific Realism and Instrumentalism

Two philosophical positions can be taken regarding the proposed "stratal reactor" model:

**Realist position**: Strata literally function as chemical reactors **Instrumentalist position**: This is merely a useful metaphorical model

**Which position would be more productive?** At this stage, an instrumentalist approach would likely be more appropriate. That is, focusing on how useful this model is for suggesting new research directions and reinterpreting existing data, rather than its "truth/falsehood."

## 5.3 The Need for Interdisciplinary Approaches

Developing such a conceptual framework would require interdisciplinary collaboration including:

- **Geochemistry**: Evaluating reaction possibilities under actual stratal conditions
- **Catalytic chemistry**: Designing organic-inorganic composite catalytic systems
- **Geology**: Modeling long-term stratal reaction processes
- **Engineering**: Exploring application possibilities for CCUS technology
- **Philosophy of science**: Examining conceptual consistency and logical validity

# 6. Limitations and Critical Considerations

## 6.1 Conceptual Limitations

The proposed framework must acknowledge the following limitations:

**Difficulty of experimental verification**: Difficulty reproducing geological timescale processes in laboratories

**Complexity problems**: Can simple reactor models adequately capture the complexity of actual stratal systems?

**Harmony with existing evidence**: Ensuring compatibility between accumulated geochemical data and new interpretations

## 6.2 Considerations on Verifiability

From Popper's falsificationist perspective, scientific hypotheses must be falsifiable. **How could the proposed "catalytic signature" hypothesis be falsified?**

Several possible falsification conditions:

- When optical activity of biomarkers matches biological origins
- Discovery of isotopic patterns not predicted by catalytic models
- Complete failure of expected catalytic reactions to proceed in laboratories

## 6.3 Science Sociological Considerations

For new conceptual frameworks to be accepted by scientific communities, the following conditions would be necessary:

- **Gradual introduction**: Progressive expansion rather than abrupt breaks with existing paradigms
- **Empirical achievements**: Success cases of new discoveries or predictions
- **Practical value**: Demonstrating utility in technology development or resource exploration

# 7. Proposals for Future Research Directions

## 7.1 Stepwise Verification Strategy

**Phase 1: Conceptual Refinement**

- Evaluating reaction validity through thermodynamic calculations
- Reanalyzing existing geochemical data
- Comparing with alternative interpretation models

**Phase 2: Experimental Exploration**

- Laboratory experiments mimicking actual stratal conditions
- Evaluating catalytic system efficiency
- Analyzing product characteristics

**Phase 3: Field Application Review**

- Pilot-scale CCUS experiments
- Economic viability assessment

- Environmental impact analysis

### 7.2 Academic Contribution Directions

**Geochemistry field**: Reinterpreting petroleum geochemistry from catalytic perspectives

**Engineering field**: Designing and optimizing stratal-mimicking reactors

**Environmental science**: Evaluating stratal reactor roles in carbon cycling

**Philosophy of science**: Petroleum formation as emergent phenomena in complex systems

## 8. Conclusion: Possibilities for New Thinking

### 8.1 Significance of Conceptual Contributions

The "stratal reactor" framework explored in this study should be understood as **a starting point for new thinking** rather than a completed theory. Its core contributions can be summarized as follows:

1. **Resolution of dichotomous opposition**: Reconstructing the biogenic-abiogenic opposition as complementary relationships
2. **Reconceptualizing organic matter roles**: New perspectives as catalysts rather than feedstock or contaminants
3. **Promoting interdisciplinary approaches**: Inducing convergent thinking among geochemistry-catalytic chemistry-engineering
4. **Technological application possibilities**: Suggesting new directional approaches in CCUS fields

### 8.2 The Role of Scientific Imagination

As Einstein said, "Imagination is more important than knowledge." Scientific advancement often begins with imagination that transcends existing conceptual frameworks. **Even if these ideas remain unverified at present, might such thought experiments provide motivation for new research?**

### 8.3 Prospects for the Future

Whether the proposed concepts actually possess validity will be revealed through future research. However, the exploration process itself could have the following values:

**Scientific value**: Reexamining limitations of existing paradigms and exploring new possibilities

**Technological value**: Contributing to developing innovative approaches for achieving carbon neutrality

**Philosophical value**: Enhancing understanding of emergent phenomena in complex systems

**Social value**: Providing new perspectives for energy transition and climate change response

### 8.4 Conclusion: Open Questions

In concluding this discussion, we pose several open questions:

1. **Ontological question**: What are the most appropriate conceptual tools for understanding petroleum's essential characteristics?

2. **Epistemological question**: How can we scientifically investigate processes occurring on geological timescales?

3. **Methodological question**: How can we harmonize reductionist and holistic approaches to complex system phenomena?

4. **Ethical question**: How should we evaluate the environmental and social impacts of new energy technology development?

**In the process of seeking answers to these questions, new possibilities for expanding scientific knowledge and creating a sustainable future for humanity may emerge.**

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*This study serves as a thought experiment that philosophically reconsiders existing discussions on petroleum origins and explores new conceptual possibilities. The empirical validity of the proposed ideas must be verified through future research.*